are they different? Compare personal costs, responsibility, solutions, etc.

6. Research and report on which governmental agencies (municipal, county, state, and federal) regulate and protect groundwater. How do these groups work together? Discuss roles that other groups play (for more information, see *Groundwater: Wisconsin's Buried Treasure*).

7. Research and report on how water resources have influenced the history of your community. How has water helped your community develop? Has groundwater played a special role? Many areas of Wisconsin are known for having "healthful" spring water. Is part of your community's history related to spring water? How does your community feel about protecting groundwater?

8. Groundwater is important in the production and processing of many Wisconsin products such as cheese, beer and paper. Investigate some of these products. How much water do they use? How clean should the water be? Are there laws or regulations that govern the quality of the water they use?

Trouble in Paradise

Learning Objectives: Students will: (1) determine the source of groundwater contamination in the mythical town of Paradise using knowledge gained from previous activities, (2) discuss the implications of groundwater contamination in Paradise and (3) recommend possible solutions to the groundwater contamination problem in Paradise.

Subjects: Environmental Education, Science, Health Education and Social Studies

WMASs: EE: A.8.4, A.8.5, B.8.10, B.8.15, B.8.17, B.8.21, B.8.23, C.8.2, D.8.1

SC: A.8.6, B.8.6, C.8.6, E.8.1

HE: A.8.2, G.8.3

SS: A.8.1, A.8.11, D.8.11

Grades: 7–9 (and up)

Materials:

- Trouble in Paradise handouts
- colored pencils—red, blue and green

Background: In this activity, wells in the mythical town of Paradise have been contaminated with volatile organic compounds (VOCs). VOCs are a group of commonly used chemicals that evaporate, or "volatilize" when exposed to air. Since they dissolve many other substances, VOCs are widely used as cleaning and liquifying agents in fuels, degreasers, solvents, cosmetics, polishes, drugs and dry cleaning solutions. VOCs are found at airports and service stations; machine, print and paint shops; electronics and chemical plants; dry cleaning establishments; and in household products. Two common VOCs—1,2-dichloroethylene and trichloroethylene—are referred to in this activity.

When VOCs are spilled or dumped, some will evaporate and some will soak into the ground. Once in the soil, VOCs can be carried deeper into the ground by percolating rainwater. If they reach the water table, VOCs can persist for years because the cool, dark, low-bacteria environment does not promote decomposition. If VOCs in groundwater migrate to nearby wells, they can end up in someone's drinking water.

At least one VOC has been detected in about 2,500 drinking water wells in Wisconsin. Over 80 different VOCs have been found in Wisconsin's groundwater, with trichloroethylene being the VOC most commonly found. Some 770 private or public water supply wells have had concentrations of at least one VOC above a Wisconsin groundwater standard.

Some VOCs can harm the central nervous system, liver and kidney. For these types of health effects, researchers can determine a "no-observable-effect level"— a maximum VOC dose that does not produce any effect in exposed experimental animals. This "no-observable-effect level" is further reduced by a safety factor, which ranges from one tenth to one ten thousandth (depending on the strength of scientific evidence). From this number state groundwater standards are established.

Some VOCs (such as trichloroethylene) are known or suspected carcinogens (cancer-causers). State groundwater standards for carcinogens in drinking water are conservatively set so that lifetime consumption of the water will cause no more than 1 to 10 additional cancers for every million persons exposed. Additional information on how Wisconsin groundwater quality standards are developed can be found in Wisconsin's groundwater law, chapter 160, Wis. Stats., at: **legis.state.wi.us/statutes/1993/93stat0160.pdf**. Chapter NR 140, Wis. Administrative Code, contains the groundwater quality standards that have been adopted in Wisconsin. NR 140 can be found online at: **legis.state.wi.us/rsb/code/nr/nr140.pdf.**

Federal drinking water standards (Maximum Contaminant Levels) are set in a similar manner by the U. S. Environmental Protection Agency. Check out **epa.gov/safewater/standards.html** for information on how federal drinking water standards are developed.

Several factors influence a well's vulnerability to VOC contamination. One factor is the distance between the well and the source or sources of contamination. Another factor is time. Groundwater usually moves very slowly and it can sometimes take years for a spilled contaminant to reach nearby wells. The time and distance contaminants must travel are extremely important because many wells which presently show no contamination may eventually become contaminated by spills that have already occurred. In other words, we may not know the full effects of contamination we already have caused for many years to come (For more information, see *Groundwater: Wisconsin's Buried Treasure*).

There are two options for dealing with VOC contamination. The well owner can either construct a new well or treat water from the contaminated one. Treatment of the well water has the benefit of removing contaminated water from the ground. Both options are expensive. Drilling a new municipal well can cost as much

as $1 million or more; building a water treatment facility for a contaminated municipal well generally costs between $500,000 and $1 million.

Activity setting:

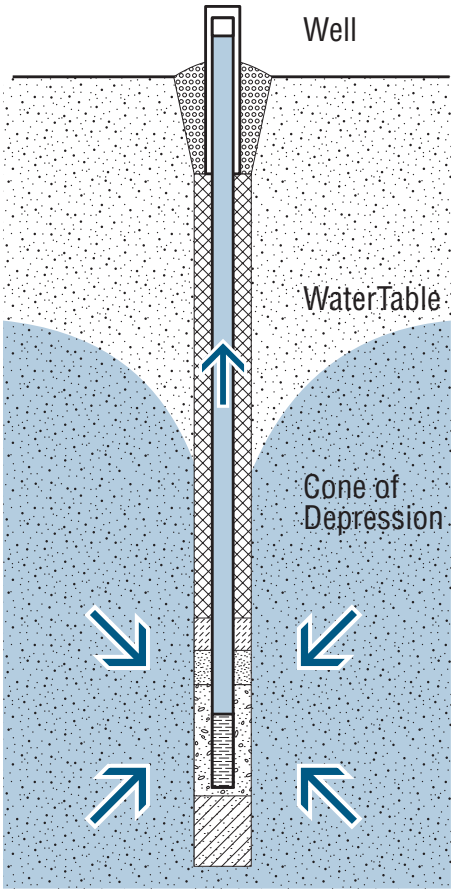
VOC contamination has occurred in "Paradise" and your students will be asked to determine where the VOCs came from and what should be done about the problem. The contamination was first noticed after the installation of a high capacity community well. Wells that draw a large volume of water can affect the direction and rate of groundwater flow by creating a "cone of depression." As groundwater is depleted under the well site, it is replaced by groundwater from soils surrounding the well. So even water that initially flowed away from the well can be drawn toward it as groundwater immediately under the well is removed.

The new municipal well in "Paradise" has created a cone of depression and is drawing water and the plume of VOC contamination toward itself. The source of contamination is the closed landfill at the Johnson farmsite which, while it operated, may have accepted wastes containing VOCs from local industries and households. This landfill was designed as a "natural attenuation" site, meaning that the landfill depended only on the characteristics of surrounding soils to contain and filter leachate from the waste deposited there. Today landfills must be lined with a layer of impermeable clay which helps to contain leachate. Modern waste disposal regulations also limit the type of wastes that can be deposited in a municipal landfill.

Note: The groundwater standard listed for 1,2-dichloroethylene (1,2-DCE) on the activity sheets is actually the groundwater standard for 1,2-dichloroethylene (cis), which is an isomer of 1,2-DCE. On the activity sheets, 1,2-DCE is considered to be one substance to simplify the exercise.

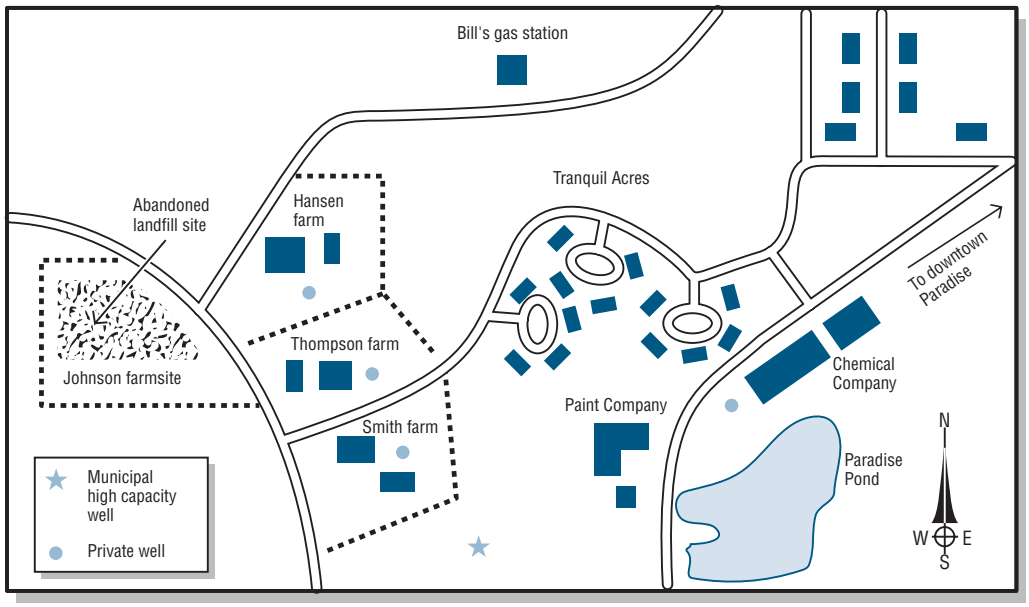
Procedure:

1. Using How Much is a Part per Billion? handout, discuss the idea of parts per trillion (ppt), parts per billion (ppb) and parts per million. Explain that drinking water standards and laboratory results are often stated in micrograms per liter (µg/L) which is equivalent to ppb. Because it's easier to understand the concept of ppb than µg/L, the Trouble in Paradise Activity Sheets use parts per billion.
2. Tell students that the mythical town they will be investigating is based on several Wisconsin communities that actually experienced groundwater contamination. Explain what VOCs are and their many sources. Briefly discuss how groundwater standards are set in Wisconsin.
3. Distribute "Trouble in Paradise" handouts. Have students read the case study.
4. Ask individual students to read aloud the problems on the activity sheet. Clarify any uncertainties about the problems.
5. Working in small groups, complete the activity sheet. Remind students that they will need to use the information given in the case study AND what they have learned in previous activities to answer the questions. It may be helpful to review the reading of topographic maps.
6. Using the completed worksheets, construct a master time line on the chalkboard. Discuss the time line and answers to activity sheet questions.
   - ❖ In what general direction does groundwater flow in Paradise?
   - ❖ What is the source of contamination? How do you know?
   - ❖ Where would you place test wells to confirm the source of contamination?
   - ❖ What is a plume of contamination?
   - ❖ How did the shape of the plume of VOC contamination change? What caused it to change?

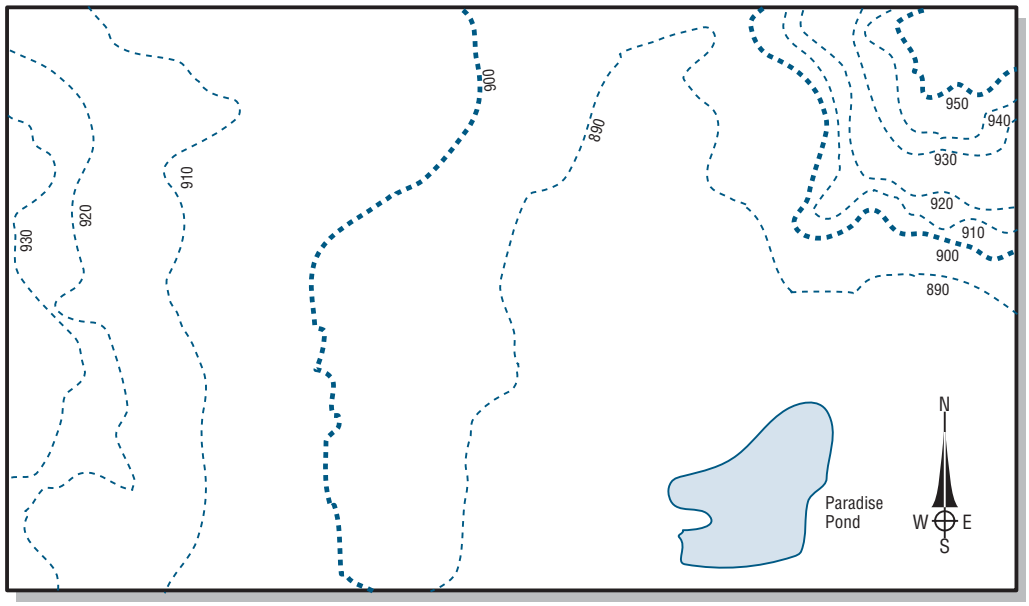


   - ❖ Why did it take so long for the VOCs to move from their source into surrounding wells?
   - ❖ Why did the contamination appear in the Hansens' well then seem to disappear?
   - ❖ Why was there such a delay between the time that VOCs were first discovered in the Hansens' well and when city officials decided to take action?
7. Discuss the implications of groundwater contamination in Paradise.
   - ❖ What are VOCs used for?
   - ❖ Who might have put materials containing VOCs in the landfill?
   - ❖ When is groundwater "contaminated"? Is water that contains 200 ppb 1,2-dichloroethylene considered contaminated? Is 200 ppb 1,2-dichloroethylene considered unhealthy?
   - ❖ Does contaminated necessarily mean unhealthy?

- ❖ Why do you think the groundwater standard for 1,2-DCE is so much higher than the MCL for trichloroethylene (TCE)?
- ❖ Who's to blame for the contamination?
- ❖ Who should pay to solve the problem?
- ❖ How did the citizens react to the contamination? Were their demands reasonable? What else could citizens do?
- ❖ How did the contamination affect private well owners?
- ❖ Should the Smiths' and Thompsons' well water be restored (either by construction of a new well or by treating water from existing wells)? If so, who should pay?
- ❖ Could the contamination affect the new community well?
- ❖ How long can Paradise's problem continue?
- ❖ If hazardous materials are removed from the landfill in Paradise, they may have to be moved to a hazardous waste landfill in another state. Is that fair? Who should pay to maintain and operate the disposal site?
- ❖ Could the contamination have been avoided? If so, how?
- ❖ What can Paradise do about the contamination now?
- ❖ Could your community have problems like this?
- ❖ How can your community help prevent groundwater contamination problems?



Map A



Map B

Going Beyond:

Going Beyond:

1. Using selected discussion questions as an outline, research and report on a groundwater contamination issue in your area.
2. Use the websites listed in this exercise as a starting point to learn how Wisconsin groundwater standards and federal Maximum Contaminant Levels are established. Look at the similarities and differences in how health standards are set and in which substances have standards at the state and federal level.
3. Have your students do calculations to understand the concepts of 1 part per million, 1 part per billion and 1 part per trillion. For example, how long is 1 million seconds? How long is 1 billion feet?

Adapted from: *Discovering Groundwater: A Supplementary Activities Guide for Upper Elementary Social Studies and Science Classes,* 1984, Wisconsin Department of Natural Resources, Western District (out of print).

Trouble in Paradise Activity Sheet

The mythical town of Paradise is a rural township of about 5,000 people. Most residents run small farms or local services and businesses. The rolling countryside of the township has attracted urban workers in recent years from the nearby city of Crystal Springs and the town is experiencing its first major growth period in 20 years.

A small industrial area lies just west of downtown Paradise. This area includes a paint manufacturing company and a chemical plant. Both of these industries use water in their manufacturing processes and both produce chemical wastes. The paint and chemical companies were built in the late 1950's. In 1965, a municipal landfill was built west of the industrial site. The landfill accepted 500,000 cubic yards of municipal and industrial waste from 1966 until the landfill was covered in 1975.

The landfill site was sold to Jean Johnson for farming in 1977; the farm house was destroyed by fire in 1993, and the land was sold for suburban development in 1994. A gas station was opened near the farm site in 1995.

Through the early 1970's, all Paradise residents drew their drinking water from private wells. As more and more people moved into Paradise, residential neighborhoods expanded to the west and what had been farmland became suburban neighborhoods. In 1978 Paradise incorporated as a city. A new subdivision, Tranquil Acres, was developed between the industrial area and the Johnson farmsite during the early 1990's. Subdivision plans called for one high capacity well to serve the new homes. The well was installed in 1997 and began pumping water in February 1998.

In April 1998, members of the Hansen family began experiencing nausea, vomiting and blurred vision. The Hansen home is one of three remaining farms in Paradise and is located about ½ mile west of Tranquil Acres. Their home was built in the early 1900's and has its own private well. The Hansens suspected that their well water was causing their symptoms and in May 1998 they contacted the city health department. The city health department did not have the means to detect many contaminants, so they called in county health officials.

In June 1998, lab samples drawn by the county showed that the Hansen's well contained volatile organic compounds (VOC's), including trichloroethylene (TCE) and 1,2-dichloroethylene (1,2-DCE). The well samples contained 7 parts per billion (ppb) TCE and 350 ppb 1,2-DCE. County health officials advised the Hansen family to use bottled water for drinking and to minimize contact with water by taking shorter, cooler showers, running the exhaust fan during showers, ventilating the bathroom after showering, and opening kitchen windows when running the dishwasher.

VOC	Sources	Health effects	Wisconsin groundwater standard
1,2-dichloroethylene (1,2-DCE)	manufacturer of industrial solvents, coolant, beakdown product of TCE, landfill leachate	nausea, vomiting, weakness, tremors, liver and kidney damage, possible mutagen	70 ppb
Trichloroethylene (TCE)	paint remover, metal degreaser, dry cleaning solvent, manufacture of organic chemicals, landfill leachate	blurred vision, nausea, vomiting, damage to kidney, liver and nervous system, possible carcinogen	5 ppb

Between June 1998 and April 1999, local wells were monitored for VOC's. Each well was tested three times.

Well	June 1998		February 1999		April 1999	
	1,2 -DCE	TCE	1,2 -DCE	TCE	1,2 -DCE	TCE
Hansen's farm	350	7	50	0	0	0
Thompson's farm	70	0	188	1	290	1
Smith's farm	0	0	0	0	0	0
Paint company	0	0	0	0	0	0
High capacity well	0	0	0	0	0	0
Note: Results are in parts per billion (ppb)						

The Hansen's well showed high levels of VOC's in June 1998, but only traces of VOC's in February 1999. By April 1999, the contaminants seemed to have disappeared from the Hansen well. In June 1999, the Smith's began to experience the same symptoms that the Hansens had experienced in 1998. The Smiths called the county health department to report the problem. Paradise officials decided a full scale investigation was in order. They feared that the contamination might be drawn toward the new high capacity well in the subdivision.

The area wells were sampled again in May and July 1999 with the following results:

Well	May 1999		July 1999	
	1,2 -DCE	TCE	1,2 -DCE	TCE
Hansen's farm	0	0	0	0
Thompson's farm	360	2	410	6
Smith's farm	200	0	260	1
Paint company	30	0	30	0
High capacity well	0	0	0	0
Note: Results are in ppb				

Public health officials advised the Thompsons and the Smiths to use bottled drinking water and minimize contact with their well water. In addition to TCE and 1,2-DCE, water tests revealed that the Thompson's well was also contaminated with methane gas produced by decaying organic material. Methane gas can be carried underneath homes by groundwater where, in high enough concentrations, it can cause explosions.

After hearing the results of the health department tests, residents of Tranquil Acres formed a citizen action group. They feared that the high capacity well was in danger of being contaminated. After several meetings citizens petitioned the city to:

1) Guarantee that the VOC problem be solved before the contamination spread to the new community well.
2) Guarantee alternate sources of water for contaminated wells.
3) Guarantee purchase of affected properties to maintain property values if the contamination problem cannot be solved.

In August 1999, city council members determined that monitoring, testing and clean up could cost up to 3 million dollars. They have hired your company, the Contamination Busters, to help solve their groundwater problem before the community well is affected. Based on what you know about groundwater and the information you have been given, complete the following report sheet for the city council.

1. Place letters representing the following events on the timeline below:

   A: Tranquil Acres is developed

   B: landfill is constructed

   C: citizens form action group

   D: landfill is covered

   E: Smiths contact hea lth department

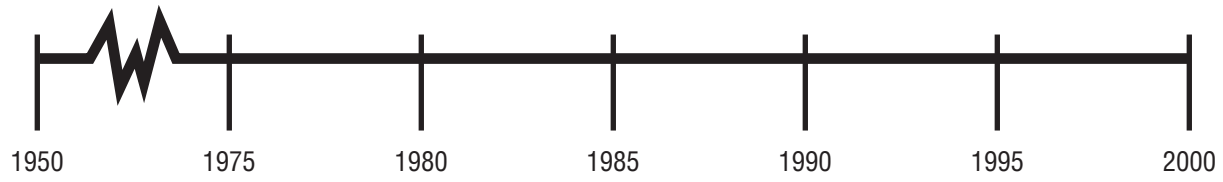
   F: local industries are built

   G: city council decides to take action

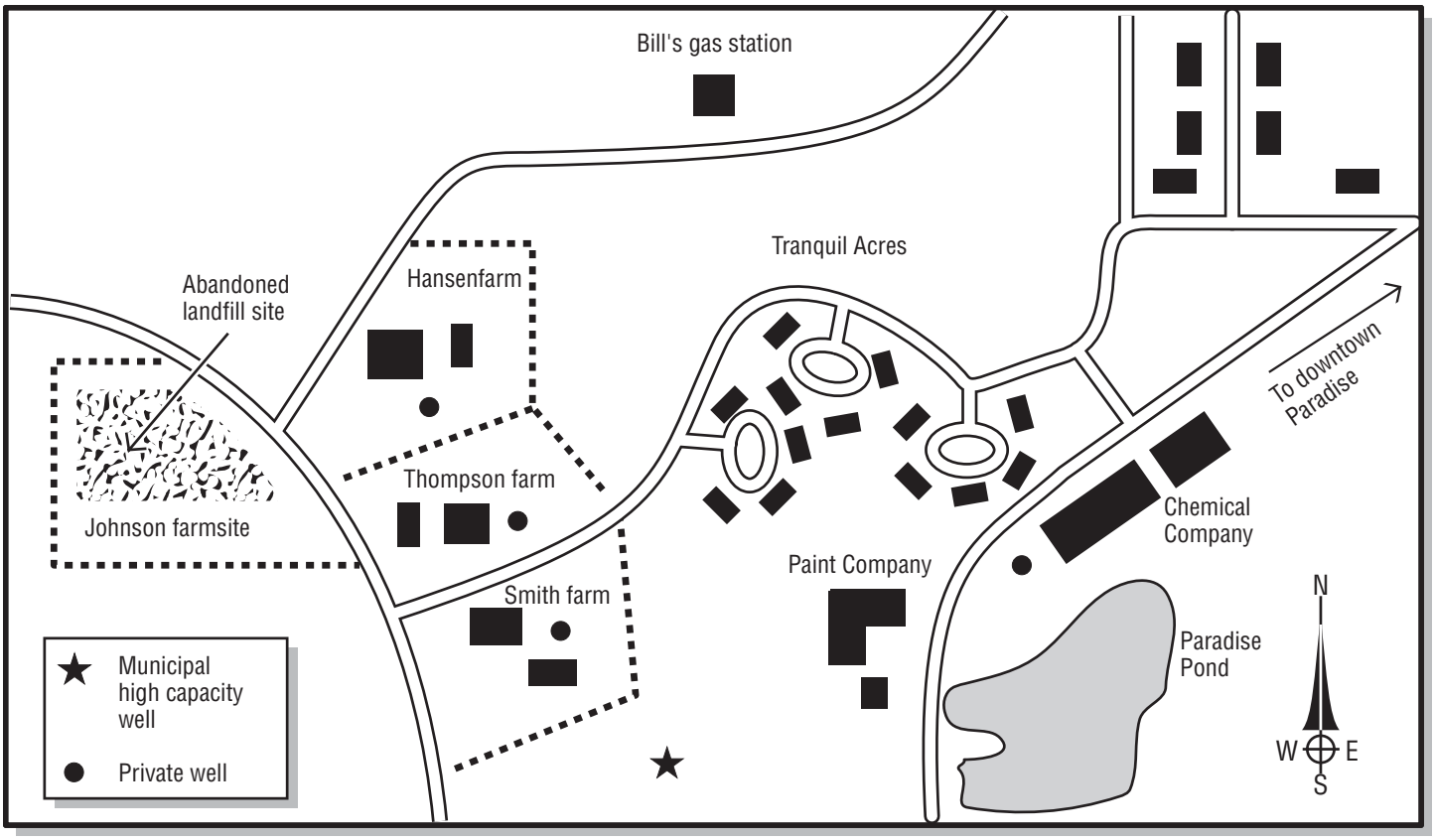
   H: high capacity well begins pumping

   I: Bill's gas station opens

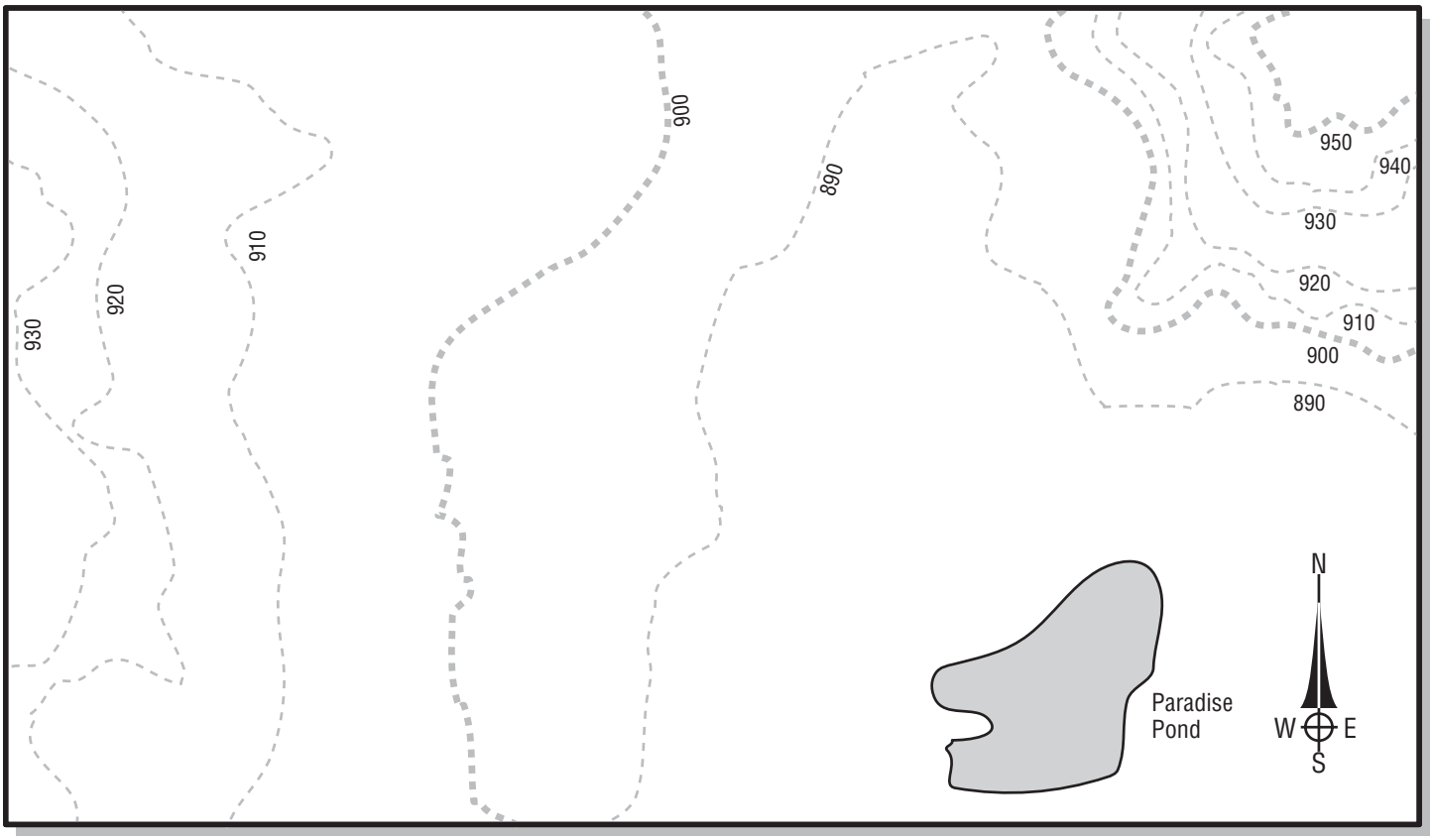
   J: Hansens contact health department



2. Based on the topography of the Paradise area, draw an arrow on the map "B" showing the general direction of groundwater flow.


Bill's gas station
Tranquil Acres
Abandoned
landfill site
Hansenfarm
Thompson farm
Johnson farmsite
Smith farm
Paint Company
Chemical
Company
To downtown
Paradise
Paradise
Pond
Municipal
high capacity
well
Private well
N
W
E
S

Map A


900
890
910
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950
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910
900
890
Paradise
Pond
N
W
E
S

Map B

3. Complete the following tables.

Well	Parts per Billion 1,2-Dichloroethylene				
	June 1998	February 1999	April 1999	May 1999	July 1999
Hansen's farm					
Thompson's farm					
Smith's farm					
Paint company					
High capacity well					

Well	Parts per Billion Trichloroethylene				
	June 1998	February 1999	April 1999	May 1999	July 1999
Hansen's farm					
Thompson's farm					
Smith's farm					
Paint company					
High capacity well					

4. Circle all VOC levels on the tables above that exceed Wisconsin's groundwater standards.

5. Based on the information you have gathered, what is the source of VOC contamination?

6. With a **Red** pencil place X's on map "A" in places where you'd like to put monitoring wells to confirm the source of contamination.

7. Using the information on the data tables above, outline the plume of contamination before the high capacity well was built with a **blue** pencil. With a **green** pencil, outline the plume of contamination after the high capacity well was began pumping. Why did the plume change?

How Much is a Part per Billion? Activity Sheet

Many water quality standards are measured in parts per million (ppm), parts per billion (ppb) or even parts per trillion (ppt) of pollutant in a given quantity of water. Regardless of what is being measured, ppm, ppb or ppt mean that there is one part of something in a million, billion or trillion parts of something else. The following table will help you understand this concept:

Unit	ppm	ppb	1 ppt
length	1 inch in 16 miles	1 inch in 16,000 miles	1 inch in 16,000,000 miles (a 6 inch leap on a journey to the sun!)
time	1 minute in 2 years	1 minute in 2,000 years	1 minute in 20,000 centuries
money	1 cent in $10,000	1 cent in $10,000,000	1 cent in $10,000,000,000

Very small amounts of some pollutants can harm people and wildlife.

For example:

ppm	ppb	ppt
If there is 1 ppm oil in the water, ½ of the Dungeness crabs will be killed	At levels of 20 ppb of Mercury in their blood, humans show symptoms of mercury poisoning	Brook trout cannot grow properly or reproduce at levels of toxaphene over 39 ppt

Adapted from C. Revelle and P. Revelle, The Environment, 1988, p. 112-114, Boston: Jones and Bartlett Publishers, Inc.